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(54) **Angular velocity sensor and manufacturing process**

(57) The angular velocity sensor 18 is manufactured from a silicon-on-insulator (SOI) wafer. An oscillating structure 19 is constructed from the bulk substrate material of the SOI wafer and displaceable Coriolis acceleration sensors 2, 3 are constructed on it from the SOI layer of the wafer. Such an integrated construction results in a low thickness tolerance and low stress gradient in the SOI layer enabling high accuracy measuring. The manufacturing process involves bonding a first silicon wafer having a highly doped and a second lowly doped epitaxial layer, by the epitaxial layer to a second oxidised silicon wafer, etching the first silicon wafer away up to the highly doped layer, selectively etching the highly doped layer, constructing a displaceable acceleration sensor from the epitaxial lowly doped layer by photolithography and etching and then forming the oscillating structure from the second silicon wafer by plasma etching. An electronic evaluating circuit 7 can also be integrated into the sensor.

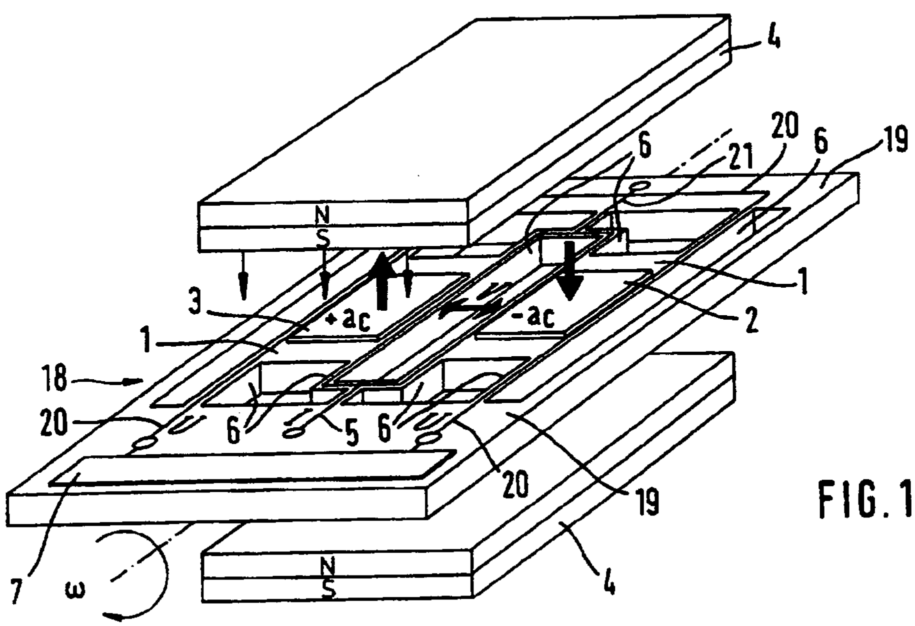

FIG. 1

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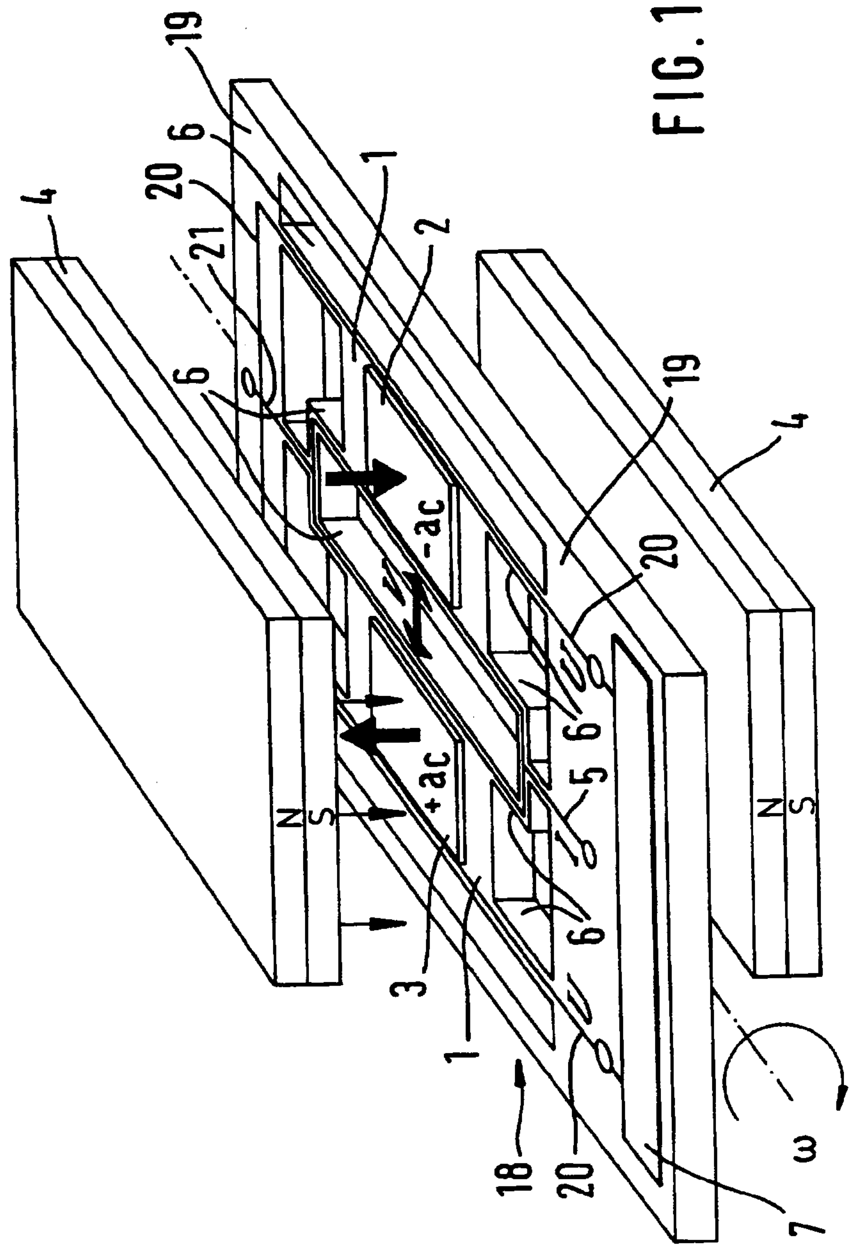

FIG. 1

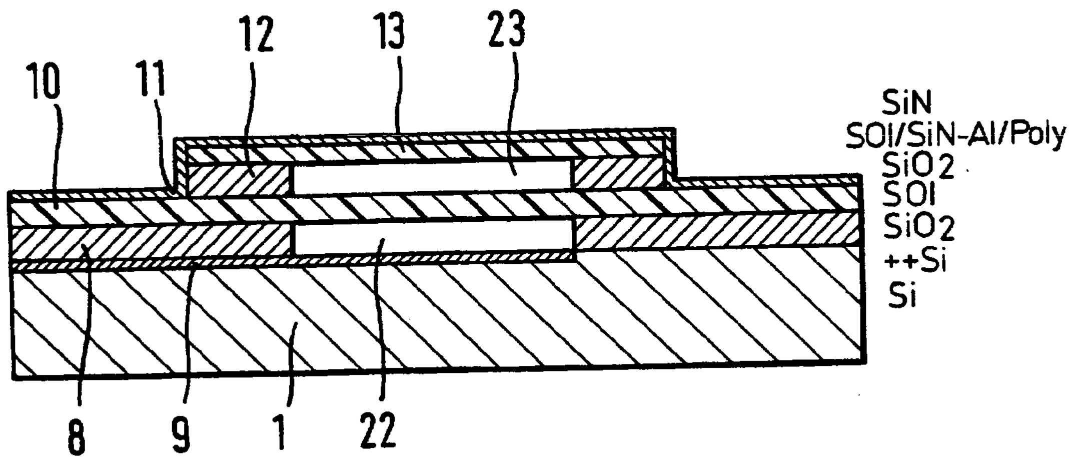

FIG. 2

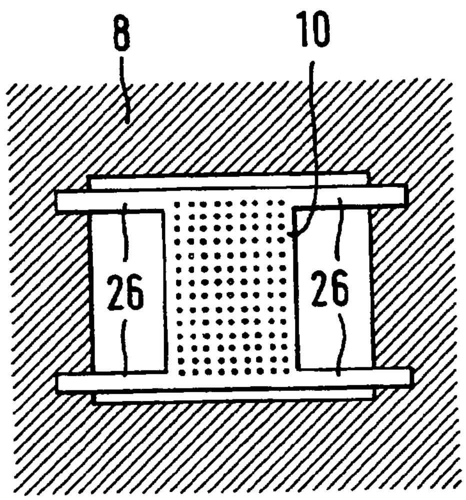

FIG. 3

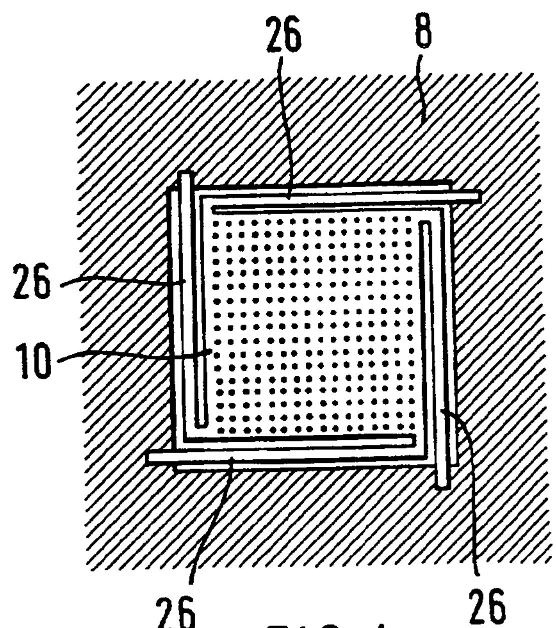

FIG. 4

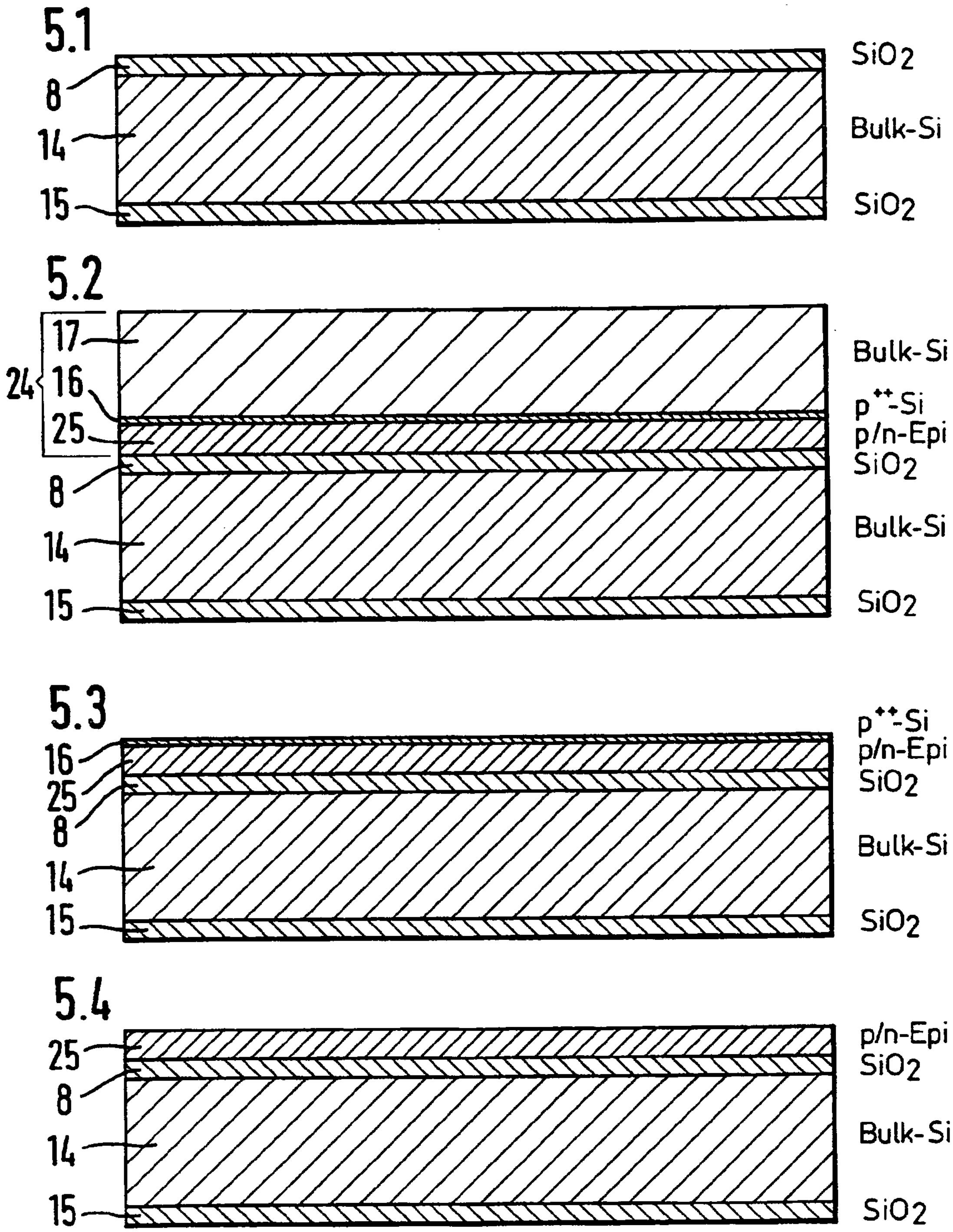
5.1
8
14
15
SiO2
Bulk-Si
SiO2
5.2
24
17
16
25
8
14
15
Bulk-Si
p++-Si
p/n-Epi
SiO2
Bulk-Si
SiO2
5.3
16
25
8
14
15
p++-Si
p/n-Epi
SiO2
Bulk-Si
SiO2
5.4
25
8
14
15
p/n-Epi
SiO2
Bulk-Si
SiO2

FIG. 5

Angular velocity sensor and process for manufacturing an angular velocity sensor

Prior art

The invention is based on an angular velocity sensor according to the preamble of independent Claim 1 and on a process for manufacturing an angular velocity sensor according to the preamble of independent Claim 4. Published German patent application DE-40 32 559 discloses an angular velocity sensor that has an oscillating substrate structure on which a displaceable acceleration sensor is arranged. The substrate structure is made wafer-thick by wet etching in hot caustic potash solution and, as a result, is subject to serious geometrical constraints. The acceleration sensor is constructed from precipitated polysilicon or precipitated monocrystalline silicon.

Advantages of the invention

In contrast, the angular velocity sensor according to the invention, with the features of independent Claim 1, has the advantage that the angular velocity sensor is constructed from a silicon-on-insulator wafer. The displaceable capacitive acceleration sensor is made from the above SOI layer. Since the SOI layer has particularly low stress, is well defined in relation to mechanical sensor properties and is free from stress gradients, a very accurate acceleration sensor with high detection sensitivity can be obtained. In addition, the electrical insulation between the elements of the SOI layer structure and the substrate is very good.

On the other hand, the process according to the invention, with the features of independent Claim 4, has the advantage

that a silicon-on-insulator layer which has a particularly low stress gradient can be simply produced.

The steps cited in the sub-claims are advantageous developments and improvements of the angular velocity sensor stated in independent Claim 1 and of the process stated in independent Claim 4. It is particularly advantageous if the evaluation electronics unit for the measuring signals is integrated into the acceleration sensor. This produces a particularly compact form of construction for the angular velocity sensor.

Drawing

An exemplary embodiment of the invention is illustrated in the drawing and is explained in further detail in the description which follows. Figure 1 shows an angular velocity sensor, Figure 2 a section through an acceleration sensor, Figure 3 a first structure of an acceleration sensor, Figure 4 a second structure of an acceleration sensor and Figure 5 process steps for manufacturing a silicon-on-insulator layer.

Description of the exemplary embodiment

Figure 1 shows a schematic view of an angular velocity sensor structure 18, which is constructed from silicon and which has a circumferential frame 19, two oscillating structures 1, which can be displaced as oscillating masses, being arranged in the frame 19. The oscillating structures 1 are connected to each other and to the frame 19 via flexural bars 6. The oscillating structures 1 represent oscillating masses in the form of plates, the plates being arranged alongside each other in parallel. The suspensions of the oscillating structures 1 are constructed so that the oscillating structures 1 can be made to oscillate precisely in opposite phase. An acceleration sensor 2, 3 is arranged in a displaceable fashion on each of the oscillating structures 1. In Figure 1 the acceleration

sensors 2, 3 are drawn only schematically. A control and evaluation unit 7 is arranged on the frame 19. The control and evaluation unit 7 is connected to the acceleration sensors 2, 3 via a measuring signal line 20. In addition, a drive line 21 leads from the control and evaluation unit 7 to the oscillating structures 1. The frame 19 is located in a magnetic field that is generated by two permanent magnets 4.

The oscillating structures 1 are manufactured by a plasma etching process from the bulk substrate of an SOI wafer or from a layer of the bulk substrate of the SOI wafer previously thinned by a wet chemical process. This process is described in detail in the patent specification DE 42 41 045 and enables very deep silicon structures with a choice of geometries to be manufactured. The oscillating structures 1 are therefore manufactured free of process or crystallographic constraints, as is required for optimum antiphase oscillatory characteristics.

The angular velocity sensor in Figure 1 operates as follows: Due to the current loop formed by the drive line 21, and the Lorentz force acting in the magnetic field, the control and evaluation unit 7 generates an oscillation in the oscillating structures 1 in the plane of the frame 19, as shown schematically in Figure 1 by an arrow denoted by the letter V. The drive of the drive line 21 is applied so that the two oscillating structures 1 oscillate exactly in opposite phase. If the frame 19, together with the magnetic field, is now rotated about an axis of rotation that runs perpendicular to the direction of oscillation of the oscillating structures 1 and perpendicular to the measuring direction of the acceleration sensors 2, 3, then Coriolis forces act upon the first and second acceleration sensors 2, 3 in the measuring direction of the sensor. The Coriolis force is calculated according to the following formula:

$a_c = 2V \times \omega$, where ω is the angular velocity about the axis of rotation and V represents the instantaneous velocity of the oscillating structures 1 oscillating in antiphase.

The Coriolis forces are shown schematically in Figure 1 by arrows and are denoted by the letters ac. The mode of operation of angular velocity sensors is sufficiently well known and is described, for example, in the publication DE-OS 40 32 559.

Figure 2 shows a cross-section through an oscillating structure 1 and an acceleration sensor 2, 3 that can be displaced perpendicularly to the surface of the oscillating structure 1. A first silicon oxide layer 8 is deposited on the oscillating structure 1, which consists of silicon, a recess being placed in the first silicon oxide layer 8. A first silicon-on-insulator (SOI) layer 10 is placed on the first silicon oxide layer 8. A second silicon oxide layer 12, in which a second recess 23 is placed, is deposited on the first SOI layer 10. The first and second recesses 22, 23 are arranged one above the other. A second SOI layer 13, for example, is deposited on the second silicon oxide layer 12. The first and second SOI layers 10, 12, are covered by a silicon nitride layer 11 as additional passivation. However, the silicon nitride layer is not absolutely necessary. A highly doped silicon zone 9 is introduced into the oscillating structure 1 under the recess 22. The highly doped silicon zone 9, the first SOI layer 10 and the second SOI layer 13 form a capacitor. The first SOI layer is structured so that under the effect of a Coriolis force, a displacement takes place in the direction of the second SOI layer 13 or in the direction of the highly doped silicon zone 9. Simple angular velocity sensors have a capacitor structure which consists only of the highly doped silicon zone 9 and the structured first SOI layer 10. The second SOI layer 13 increases the accuracy of the measurement, but is not absolutely necessary.

Figure 3 shows a schematic view of a first SOI layer 10, which is constructed as a plate and is connected via four webs 26 to the first silicon oxide layer 8. The four webs 26 are placed at the four corners of the plate-type first SOI layer 10, two of the webs being arranged parallel to the other two and at right-angles to the outer edge of the plate-type first SOI layer 10. The SOI layer 10 acts as an oscillating mass.

The first and second recesses 22, 23 are installed either prior to the deposition of the first or second SOI layer 10, 13, respectively, by means of etching processes, or are produced after deposition of the first or second SOI layer 10, 13, by undercutting the structured SOI layers 10, 13. Undercutting of the SOI layers 10, 13 is accelerated so that holes are etched in the SOI layers 10, 13, and the first and second recesses 22, 23, are etched above these holes.

Figure 4 shows a further structure of the first SOI layer 10, which is constructed as a plate and is connected via four webs 26 to the first silicon oxide layer 8. The arrangement of the webs 26 in Figure 4 is chosen so that each web is routed along an outer edge and is attached to a corner point of the square, first SOI layer 10. Given the specified dimensions 23, this enables the webs 26 to be made as long as possible.

The first SOI layer 10 can also be constructed in the form of suspended comb structures, so that the first SOI layer 10 can be laterally displaced in the plane, i.e. parallel to the surface of the oscillating structure 1.

The first SOI layer 10 in Figures 3 and 4 has through-holes. The through-holes are placed in the first SOI layer 10 to accelerate the undercutting of the first recess 22 of the first silicon oxide layer 8. The corresponding process is used in the case of the second SOI layer 13 and the second recess 23. Since the etching medium has uniform access to the first

silicon oxide layer 8 through the holes, the etching process is accelerated when the first recess 22 is etched.

Figure 5 shows a process for manufacturing an SOI wafer structure for an angular velocity sensor. Figure 5.1 shows a silicon wafer 14 onto whose upper side the first silicon oxide layer 8 is deposited and onto whose underside a third silicon oxide layer 15 is deposited. The first and third silicon oxide layers 8, 15 are deposited by means of thermal oxidation, for example. An epitaxial wafer 24 is bonded onto the silicon wafer 14 in such a way that the epitaxial layer of the epitaxial wafer 24 is supported by the first silicon oxide layer 8. The epitaxial wafer 24 consists of an epitaxial layer 25 which has the desired doping and is deposited on a highly doped P+ silicon layer, which in turn is grown on a silicon bulk substrate 17, as shown by Figure 5.2.

The bulk silicon layer 17 is then selectively back-etched up to the highly doped P+ stop layer. This is illustrated in Figure 5.3. A mixture of 5% NH_3 in H_2O with a per thousand H_2O_2, which has a particularly high selectivity in relation to P+ doped silicon, can be advantageously used for this. The highly doped silicon layer is then likewise selectively removed by a mixture of HF/HNO_3 and CH_3COOH. An initial SOI layer 10, which is represented by the epitaxial layer 25 in Figure 5.4, is obtained in this way.

This process produces very precisely defined thicknesses of the SOI layer, which in this case is represented by the epitaxial layer 25. This is particularly advantageous in the case of a low layer thickness of between 2 to 5 μm. The greater amount of manufacturing effort compared to grinding and polishing is justified in that a very much lower thickness tolerance of the thin SOI layer is obtained, which is particularly required for out-of-plane acceleration sensors.

With thicker SOI layers exceeding 5 μm, a simpler process suffices, in which a silicon wafer which itself already has the desired doping, is bonded to an oxidised silicon wafer and is then mechanically ground down and polished to a predetermined thickness. SOI layers produced by this simple process have a thickness tolerance of +/- 0.5 μm. SOI layers with a thickness greater than 5 μm and a thickness tolerance of +/- 0.5 μm are used to advantage in laterally-sensitive capacitive acceleration sensors.

An oscillating structure 1 with an acceleration sensor 2 mounted upon it is constructed from the silicon-on-insulator-silicon construction illustrated in Figure 5.4 by means of photo-lithographic processes and a plasma etching process, as described in patent specification DE 42 41 045. Here, the acceleration sensor 2 consists of the epitaxial layer 25, and the oscillating structure 1 is constructed from the bulk silicon wafer 14. The oscillating structures 1 and the flexural bars 6 are constructed by means of the stated silicon deep-trench process.

In simple cases, one oscillating structure can also be used instead of the two oscillating structures 1. However, the use of the two oscillating structures 1, which are made to oscillate in opposite phase, permits antiphase measurement of the Coriolis force. Due to a difference in electrical signals, disturbing forces acting in the region of earth gravity g, are filtered out. Given Coriolis acceleration values, which are in the region of 1 to 10 mg, this considerably improves the measurement accuracy.

The highly doped silicon layer 16 is positively doped. The epitaxial layer 25 is positively or negatively doped with the desired concentration of dopant. Furthermore, if there is to be no integration, it is possible for the epitaxial layer 25 to have the same doping concentration as the epitaxial layer

16. The HNA (CH_3COOHG, HF, HNO_3) etching step is then dispensed with.

In the case of two silicon wafers bonded via one silicon oxide layer, instead of the process illustrated in Figure 5, it is also possible to grind down one silicon wafer to a predetermined thickness by trimming techniques and produce the first SOI layer 10 by this means.

The evaluation electronics can be directly integrated in the first SOI layer 10, thus obtaining a high component density with low leakage currents and high cut-off frequency, which, moreover, is suitable for higher temperatures. Instead of the capacitive measurement of the Coriolis force, as illustrated, other detection methods such as piezoelectric or piezoresistive measurement, can of course be used. The use of SOI wafers makes it possible to obtain sensor structures with maximum dimensions of the order of square millimetres, which are absolutely planar and free of bowing.

CLAIMS

1. An angular velocity sensor with a substrate structure (18) which can be made to oscillate, onto which a displaceable acceleration sensor (2, 3) is mounted, **characterised in that** the angular velocity sensor is constructed from an SOI (silicon-on-insulator) wafer, that the substrate structure (1) which can be made to oscillate is essentially constructed from the bulk material of the SOI wafer, and that a displaceable acceleration sensor is constructed from the SOI layer of the SOI wafer to detect Coriolis accelerations.

2. Angular velocity sensor according to Claim 1, characterised in that the substrate structure is essentially constructed from bulk silicon of the SOI wafer.

3. Angular velocity sensor according to one of Claims 1 or 2, characterised in that an evaluation electronics unit is integrated in the SOI layer (2, 3) producing the acceleration sensor.

4. Process for manufacturing an angular velocity sensor according to one of Claims 1 to 3, whereby a first silicon wafer (14) having a first, thin, highly positively doped silicon layer (16) and having a second, lowly doped epitaxial layer (25) lying above said first silicon layer, is bonded via the epitaxial layer (25) to an oxidised, second silicon wafer (14), and the first silicon wafer (24) is selectively etched up to the first highly positively doped silicon layer (16), after which

the first silicon layer (16) is removed by selective etching, characterised in that the epitaxial layer (25) is constructed as an acceleration sensor by means of photolithographic and etching processes, and that an oscillating structure (1) which supports the acceleration sensor (2, 3) is constructed from the second silicon wafer (14) by means of plasma etching.

5. Process according to Claim 4, characterised in that through-holes are etched in the epitaxial layer (25), and that the first silicon oxide layer (8) is etched out in the form of a predetermined recess (23) via the through-holes.

6. Process according to Claim 4, characterised in that a predetermined recess is placed in the oxide layer deposited on the second silicon wafer (14) by means of etching processes prior to bonding to the first silicon wafer (24).

7. Process according to one of Claims 4 to 6, characterised in that an evaluation electronics unit is integrated in the epitaxial layer (25).

8. Any of the angular velocity sensors substantially as herein described with reference to the accompanying drawings.

9. Any of the processes for manufacturing an angular velocity sensor substantially as herein described with reference to the accompanying drawings.

The Patent Office

11

Application No:	GB 9601992.2	**Examiner:**	Andrew Alton
Claims searched:	1-7	**Date of search:**	25 March 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1G: GPGA,GED

Int Cl (Ed.6): G01C: 19/56

Other: Online:- WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	EP 0634629 A1 Murata Manufacturing Co. - Whole document	1-3
X	WO 92/01941 A1 Robert Bosch GmbH - See abstract	1,2

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		